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Challenges to implementing greenhouse gas mitigation measures in livestock agriculture: A conceptual framework for policymakers

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Abstract

Livestock agriculture is a significant global emitter of greenhouse gases (GHG) and the sector is under pressure to reduce its environmental footprint. Dairy, sheep and beef production are major contributors to emissions. Here, a study of the barriers to implementing GHG mitigation measures on sheep, beef and dairy farms in Wales provides insights into challenges for these sectors globally. Data were gathered from 18 stakeholder organisations and farmers using semi-structured interviews and facilitated workshops. Participants were asked about the challenges to implementing measures associated with different parts of the farming system. Data were analysed using a grounded theory approach. Identified themes covered the range of challenges to the implementation of climate-friendly agricultural practice described in a global review. A conceptual model linking categories of challenge (Practical limitations, Knowledge limitations, Cognitive limitations and Interests) was developed from the data. Comparing the findings with existing work on behavioural change revealed two major differences: i) The concept of Cognitive limitations highlighted the importance of

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cognitive processes recognised in social psychology to the implementation of change in livestock agriculture. It differentiated specific cognitive biases incorporated in behavioural models from constraints affecting the thought processes in which these biases develop and which they affect, ii) Critical elements such as power relationships and conflicting stakeholder interests were highlighted as important factors outside the scope of behavioural change models. The conceptual model developed can support policymakers in understanding and tackling challenges to change in livestock agricultural systems.

Key words: behavioural change, climate change, greenhouse gas mitigation, livestock agriculture, stakeholders

Introduction

Globally, agriculture has been estimated to contribute between 19 and 29% of total greenhouse gas (GHG) emissions (Vermeulen et al., 2012), and emissions from livestock systems, including the impacts of land use change for grazing and fodder production, have long been recognised as a particular challenge (Ripple et al., 2013; Steinfeld et al., 2006). In response, reports on climate change mitigation have emphasized the importance of reducing emissions from the agricultural sector alongside the development of a more sustainable food system that can deliver food security (Beddington et al., 2012). Much work has focussed on how best to implement climate change mitigation policies, with the scope of this literature recently reviewed at global level by the Organisation for Economic Cooperation and Development (Wreford et al., 2017). Several quantitative studies have investigated the costs of mitigation measures for agriculture (Jones et al., 2015), have studied farmers' ranking of specific mitigation measures using best-worst scaling

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(Dumbrell et al., 2016; Glenk et al., 2014; Jones et al., 2013), or have used carbon footprinting to measure and compare GHG emissions across farms in order to identify opportunities for mitigation (Hyland et al., 2016a). Quantitative tools have been developed to support stakeholders in identifying effective mitigation measures for reducing emissions in different agricultural systems (Feliciano et al., 2017).

A range of qualitative studies have also addressed decision-making in agriculture. Behavioural change theories provide conceptual models of behaviour and influencing factors, which can be applied in the land management sector (Morris et al., 2012). Attempts have been made to bring together approaches across disciplines to produce integrated behavioural models that support stakeholders working on climate change mitigation and adaptation (Darnton and Evans, 2013). Other work has examined farmers' perceptions of climate change (Hyland et al., 2016b) and the priorities and behaviour of farmers have been studied in relation to issues such as levels of engagement in agri-environment schemes (Wynne-Jones, 2013) and attitudes to entrepreneurship and the adoption of new technology (Morris et al., 2017). Actor-centred approaches such as these have produced typologies of farmers, enabling segmentation and policy targeted at specific farming groups, moving beyond homogeneous and simplified approaches that treat farmers as profit-maximisers (Jansen, 2009; Morris et al., 2017; Wynne-Jones, 2013). More recent problem-centred approaches focus on the barriers to implementing mitigation measures (Burbi et al., 2016; Feliciano et al., 2014). These studies highlight the fact that diversity in the values, beliefs and attitudes of farmers is matched by diversity of barriers to change between different regions, requiring context-specific investigation (Feliciano et al., 2014).

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The agricultural sector in Wales provides a useful case study for investigating challenges to the implementation of GHG mitigation measures: i) it is dominated by three sectors (sheep, beef and dairy production) of global importance, ii) it faces a range of wider social, economic and environmental challenges. Agriculture in Wales is shaped by the country's topography (large upland areas) and climate (high annual rainfall with cool summers), which have favoured pasture-based production dominated by sheep and beef systems, alongside a smaller but growing dairy sector in more lowland areas (Morris et al., 2017; Wynne-Jones, 2013). Eighty percent of Welsh agricultural land is classified as Less Favoured Areas under European regulations (WG, 2013) with an ageing population of farmers and a high proportion of farm businesses providing low levels of income (Morris et al., 2017). Although climate change has been part of the policy agenda for Welsh livestock agriculture for a number of years, reductions in emissions from the sector only fell by 15% between 1990 and 2015 (Jones et al., 2017) with agriculture contributing 13% of national GHG emissions figures for Wales in 2015 (Jones et al., 2017). The Welsh Government has focussed on GHG emissions reduction and long term sustainability through the Environment (Wales) Act (WG, 2016) and the Well-being of Future Generations (Wales) Act (WG, 2015), recognising that the gradual rate of change in emissions to date reflects the need for improved implementation of reduction measures. The Climate Smart Agriculture Wales (CSA Wales) project (within which the current study was undertaken) was set up to support Welsh Government in achieving this improvement, taking into account the need to combine GHG mitigation with increased systemic resilience, sustainability and food security (Lipper et al., 2014). Assessing challenges to the implementation of GHG mitigation measures is an important pre-requisite to the design of effective policy (Feliciano et al., 2014). To provide such an assessment, the current study used a qualitative approach to explore and categorise the challenges facing effective GHG mitigation in the Welsh dairy, beef and sheep sectors based on the knowledge and perspectives of relevant stakeholders. Analysis of these challenges aimed both to inform local policy approaches, and to develop a conceptual model to support the effective

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implementation of GHG emissions mitigation measures in similar livestock systems in other countries.

Methods

In order to collect the views of stakeholders on the challenges to the implementation of mitigation measures in Welsh livestock agriculture, and potential solutions to these challenges, two approaches were used. Firstly, eighteen semi-structured interviews were carried out with representatives of stakeholder organisations (Table 1), using pre-prepared general questions to facilitate discussion (Patton, 1990) (Supplementary Material A). Relevant stakeholders either affecting or affected by the implementation of on-farm mitigation measures (Freeman, 1984) were identified through a mapping process involving CSA Wales project research partners and the Agriculture Industry Climate Change Forum (AICCF) – a key Welsh research-policy-stakeholder group focussed on the relationships between agriculture and climate change. The AICCF provided a core group of industry and governmental stakeholders, acting as a starting-point from which a snowball sampling approach was used to identify further individuals for interview and for workshop involvement among the mapped stakeholder groups, following the methods of Feliciano et al. (2014). The aim in engaging a range of stakeholder groups (rather than just farmers themselves) was to identify challenges to the implementation of mitigation measures at all levels, recognising that farmers interact with other stakeholders and make choices in the context of social, economic and environmental factors influenced by actors beyond the farm. A number of stakeholder groups were successfully engaged (Table 1). Interviews lasted around one hour; the number and length of interviews was consistent with other recent studies of the agricultural sector (Morris et al., 2017).

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Following the interviews, two workshops, focussing on dairy and on sheep and beef systems respectively, were held at Aberystwyth University during October 2017. Representatives of mapped stakeholder groups, along with individual farmers identified through AICCF members, were invited to attend. A total of 22 stakeholders from 13 organisations participated in the two sessions (Table 1). Activities were organised based on the 'Futures Workshop' approach (Jungk and Müllert, 1987) in which participants work in small facilitated groups to consider ideal worlds, the barriers to reaching them and solutions to overcoming such barriers. In this case, ideal worlds were identified as the successful implementation of mitigation measures.

Table 1: Stakeholder groups and number of representatives involved in interviews and workshops

Stakeholder group	Interviews	Workshops
Agricultural industry bodies	5	4
Farm consultants / trainers	1	4
Farmers	1	5
Farming unions	2	4
Policymakers	2	4
Researchers	3	1
Rural interest groups	4	0

Challenges were identified for mitigation measures relating to six key components of the farming system: feed, animal husbandry and breeding, manure management, land management, nutrient management and energy efficiency (Supplementary Material B). Recent studies have shown that under some scenarios, the application of mitigation targets to agriculture by EU nations produces significant carbon leakage, i.e. reductions in production and emissions in one area leading to increased production and emissions in another (Huang et al., 2011) through curtailed production and an increase in imports (Fellmann et al., 2018). Therefore, discussions with stakeholders in the current study avoided those mitigation measures that could be expected to reduce production, and focussed on those aimed at: i) reducing emissions through increased production efficiency (Hyland et al., 2016a) (e.g. improving animal health and husbandry, avoiding over-use and inappropriate use of artificial fertilisers, reducing overfeeding, improved manure management), ii) improving the

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environment in which production takes place to maximise carbon sequestration (e.g. hedges and boundary trees to store carbon (Axe et al., 2017)) – these measures can also increase production efficiency, for example by providing shelter for animals, improving sward growing conditions and providing browse material for improved animal diet and health (Gregory, 1995; He et al., 2017; Mueller-Harvey et al., 2017; Pollard, 2006), and iii) adopting alternative production systems which may alter what is produced, but maintain the productive use of land (e.g. agroforestry systems which can potentially increase carbon sequestration and productivity while offering opportunities to diversify farm incomes and improve resilience to climate change (Eory et al., 2015; Nerlich et al., 2013; Rigueiro-Rodríguez et al., 2009)). Framing discussions around these types of measure also helped focus stakeholders on the specific challenges to implementing GHG mitigation measures, rather than on more general issues relating to reducing production. Within the small groups, challenges were identified by each stakeholder, listed and discussed. Facilitators worked with groups to merge duplicate challenges. Participants were then invited to suggest and discuss solutions to the challenges listed. However, in the current study, the focus was on the challenges themselves. To ensure that inputs were not biased towards more confident speakers (Kitzinger, 1995), those involved in the exercises were invited to write their ideas on sticky notes for subsequent discussion.

After the workshops, the sticky notes written by participants, information shared during group discussions, and interview data were transcribed for analysis. A grounded theory approach (Charmaz, 2014; Glaser and Strauss, 1967) was used to analyse the data; the data were coded into themes which were compared and contrasted along with the original data, in order to draw out underlying categories that could shed more light on the focus of research. Grounded theory approaches seek to get beneath the surface of the dataset; rather than trying to fit data to a pre-defined categorisation, the categories emerge from them (Charmaz, 2014; Glaser and Strauss, 1967). This type of approach was considered particularly relevant given the diversity of challenges to

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change in different locations and systems reported in previous work on climate change mitigation (Feliciano et al., 2014). The dataset reached saturation (no new themes or issues arising from successively analysed data) (Charmaz, 2014) across the interviews and workshops.

The categories arising from analysis of the stakeholder data were compared with existing literature and theory; specifically, a comparison was made with: i) a recent comprehensive global review of the barriers to and drivers of the implementation of climate-friendly agricultural practices (Wreford et al., 2017), and ii) the Individual-Social-Material (ISM) model (Darnton and Evans, 2013). These two sources were chosen as a focus, as they represent important and recent syntheses of material from this highly diverse and complex research area.

3. Results and Discussion

Twenty nine themes were identified within the data relating to challenges to the implementation of GHG mitigation measures in Welsh livestock agriculture (a full description of themes is provided in Supplementary Material C). Analysis yielded four interacting categories of challenge: Practical limitations, Knowledge limitations, Cognitive limitations and Interests. These categories are discussed in the following sections, and illustrated with relevant quotes from the data.

3.1. Practical limitations

A range of Practical limitations were revealed in the challenges identified by participants (Fig. 1). Measures may not be available or may be limited, and there may be costs related to

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implementation. Comments relating to costs included not only implementation costs, but also the costs of gathering information to tackle Knowledge limitations:

"*Optimising high end concentrates is very complex, needing a lot of knowledge and often outsourced help*"

Practical limitations also relate to nature of the farming system, and to external constraints such as regulation, availability of finance, or international trade. Comments highlighted that Practical limitations affect all actors, not just farmers. For example, the limited budgets of knowledge suppliers can hinder the implementation of change and reduce options:

"*One to one knowledge exchange is too expensive but if groups are formed only the already engaged/efficient farmers attend*"

Costs	Initial costs		"Layouts on investment affect profitability, but returns may be long term - may not be economically viable even if would like to implement"
	Running costs		"If farmer plants hedges/trees in agri-environ scheme, he still has the costs of maintenance after the scheme ends, but with no reward"
	Time / effort		"Lack of labour can limit ability to change, and may lead to easiest (rather than most efficient) system being used"
Existing system and context	Physical assets	Environment, Infrastructure, Workforce, Layout, Location	"Old infrastructure may prevent management changes such as separating animals into groups for more precision feeding"
	Organisation and finance	Production system, Ownership, Finances, Links to other systems, Policy and regulation, Socio-economic change	"Land tenure - what is allowed for tenant farmers is limited - new production systems require land lords to make the decision"
	Trade-offs	Production vs emissions, Emissions on- and off-farm Opportunity cost Production vs sustainability	"Correcting soil pH is an important issue (acidification) and this priority may not align with emissions reductions"
Options	Availability		"Some indexes are still under development (plus research for some of them - genomics of cows and microbiome - is expensive)"
	Efficacy		"Research needed here – at present moving 90% water" [centralised Anaerobic Digestion]

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Fig. 1: Practical limitations to change and its sub-categories. Dark grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right

3.2. Knowledge limitations

The data revealed a number of sub-categories making up the category of Knowledge limitations (Fig. 2). Lack of knowledge can limit change at every step from not being aware of available measures and their effects, to not having the skills to choose and implement a measure. Knowledge limitations create risk and uncertainty in relation to the theoretical impacts of a measure, its likely impact on a given system, and how this might change over time (including, for example changes in the financial situation of the farm, the effect of changing climatic conditions on the measure, or potential changes in external factors such as policy). Uncertainty about actual impacts might affect persistence with a new measure if improvements are not measured.

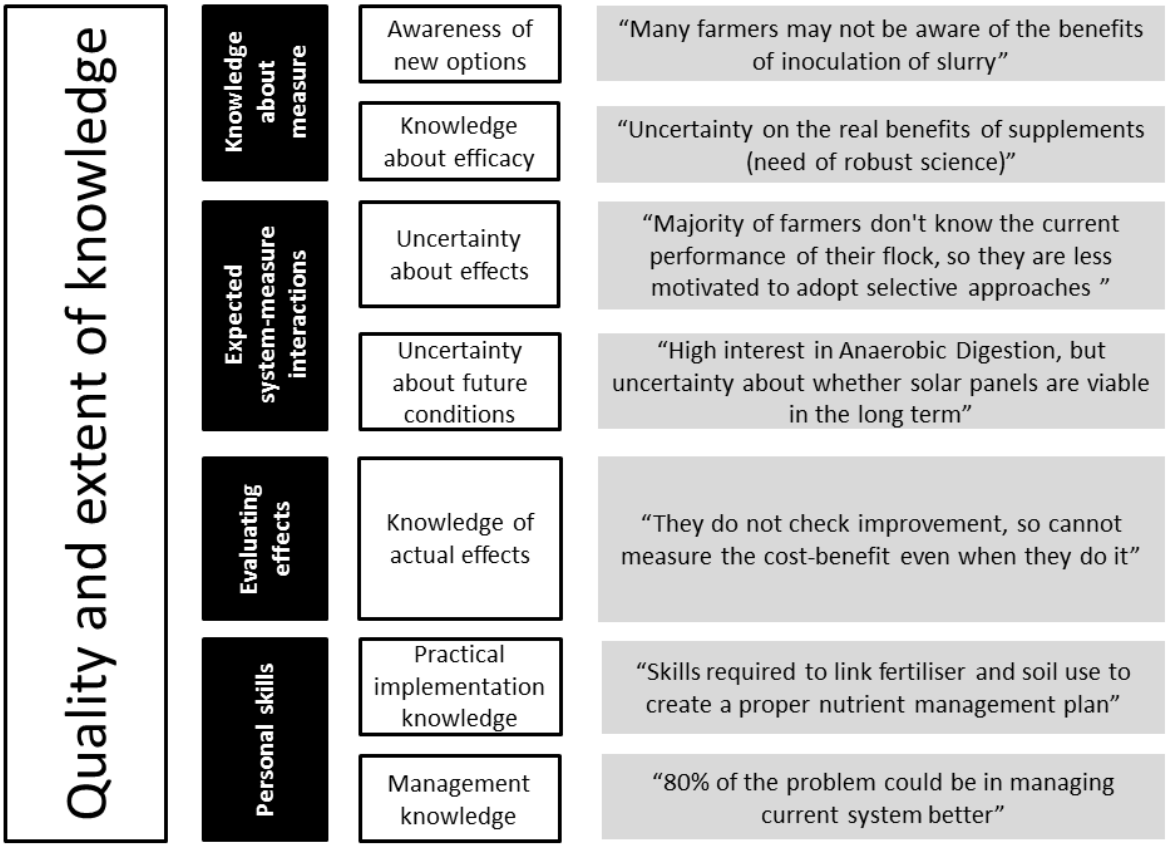

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Fig. 2. Knowledge limitations category and sub-categories. Grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right. Knowledge limitations within any sub-category can relate to either the range or the quality of knowledge held by stakeholders.

3.3. Interests

Interests (what motivates farmers and other stakeholders and what they value) and perceptions were often explicitly referred to in the data (Fig. 3). A wide range of farmers' interests and motivations were highlighted. These interests interact with the farmers' view of the system (including the nature of their stake in it) and their view of themselves and other actors (who have their own interests and perceptions which shape the system and affect change in different ways). Other actors can affect the choices of farmers directly, or via the information they provide to farmers (Quality of information, Fig. 2). If the interests of specific groups are overlooked or misinterpreted, there may be negative consequences:

"*New agri-environment schemes that do not reward management of current hedgerows etc., and recognise that the farmers signed up to previous schemes to add them, can provide an incentive to remove hedgerows, then join a scheme to be rewarded for putting them back*"

Those attempting to implement change must also be aware of historical context and its effect on interests. For example, top-down change can evoke historical events that create hostility and mistrust:

"*Afforestation can be emotive – in the past, communities* [were] *lost to reservoirs and tree planting. This has to be understood*"

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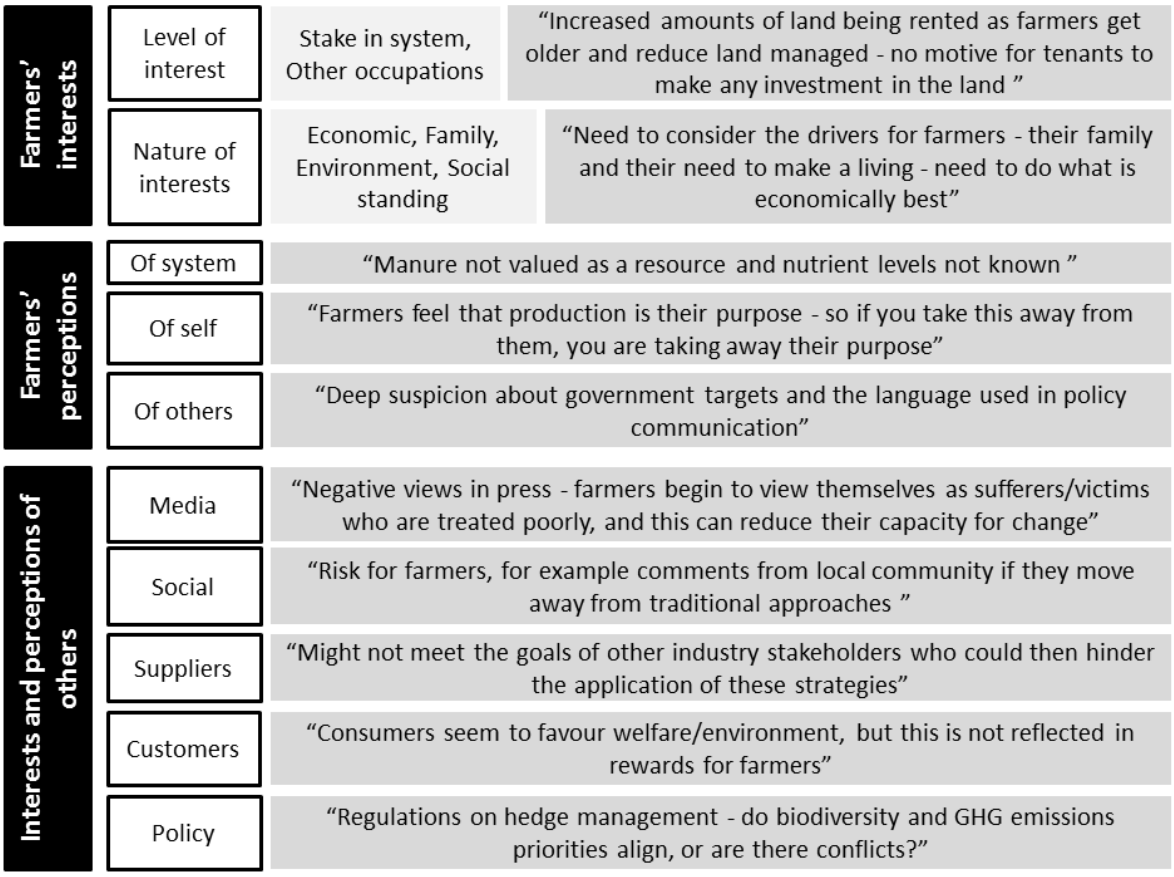

Fig. 3: Interests category and sub-categories. Dark grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right

3.4. Cognitive limitations

In contrast to issues relating to the availability and receipt of information, which are the focus of the category of Knowledge limitations, the term *cognition* is applied here to refer to the mental processes involved in *using* received information. The category of Cognitive limitations therefore reflects responses relating to constraints and pressures on the thinking processes of stakeholders (Fig. 4). Systemic complexity resulting from farm-scale processes, change in the context in which the farming system operates, and the existence of a range of interests and priorities (those of farmers and of others, like policymakers) means that management requires time, effort and skills in effective thinking (e.g. project management skills). Stakeholders faced with such challenges may develop

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coping strategies – traditional approaches or habits that enable some aspects of the system to be managed with little new thought, freeing up mental space – however, these may become obsolete or counter-productive if they remain unchanged over time. The category of Cognitive limitations reveals how the same types of factor affecting changes in behaviour (Interests, Practical, Knowledge and Cognitive limitations) also affect how stakeholders are able to think about systems. For example, farmers (and other stakeholders) may have little motivation to think about mitigation measures that lie beyond immediate concerns. Addressing Cognitive limitations therefore requires tackling another level of the four categories of challenge, as well as instilling the Interest to do so. Tackling Cognitive limitations based on a lack of skills, for example, would not entail training to implement a particular practical option, but would focus on providing training on project management or conceptual thinking. Some participants made direct reference to Cognitive limitations:

"*Constantly improving all different aspects of production, weighing up alternatives etc. is mentally hard day after day over the long term*"

These limitations are likely to affect the efficacy of stakeholder choices:

"*Dairy farmers are often at the limit of what they can afford to do, just to survive - this pressure can prevent an integrated approach to land management that takes into account interactions, long term change etc.*"

When Cognitive limitations exist, new knowledge, opportunities or demands may be ineffective in producing change, because stakeholders will not be able to process new information and/or evaluate its full implications.

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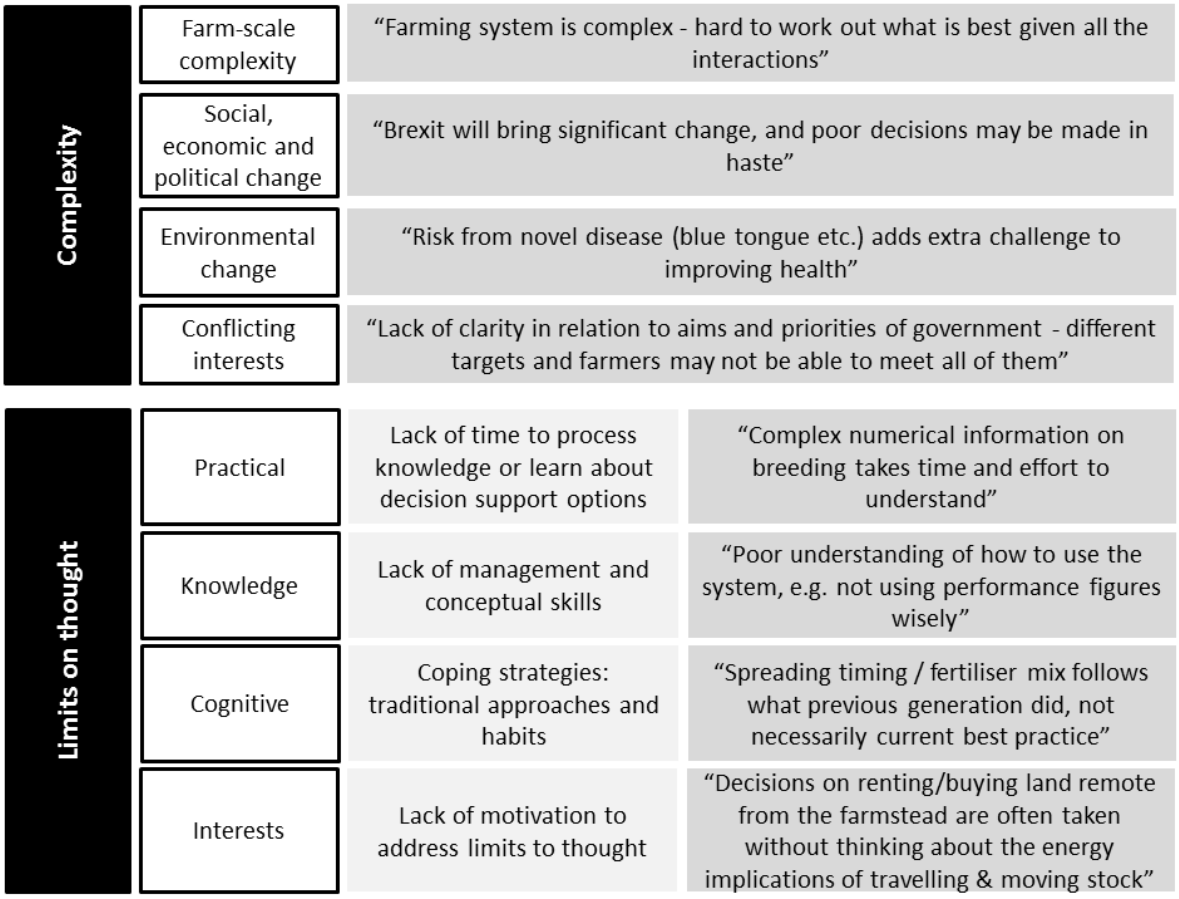

Fig. 4: Factors creating conditions under which the Cognitive limitations of stakeholders may be reached or exceeded. Dark grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right.

3.5. Conceptual framework

Putting together the categories described, the Interests of farmers and other stakeholders interact with Practical and Knowledge related limitations to change, and with the context in which change occurs (Fig. 5). Challenges can be perceived as lying on a continuum from being wholly based on Practical and/or Knowledge limitations to being wholly based on Interests not aligned with implementation. Cognitive limitations affect the ability to understand one's own interests fully, and to recognise limitations, as well as the ability to subsequently reflect on both limitations and interests and act accordingly. Given that understanding a problem and applying management and

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thinking skills to solve it must underpin action, Cognitive limitations bound subsequent processes of realised change. The whole process is influenced by its context, including other actors with their own limitations and interests, who may affect the way that the focus stakeholder perceives their interests, understands their limitations, and chooses options for change.

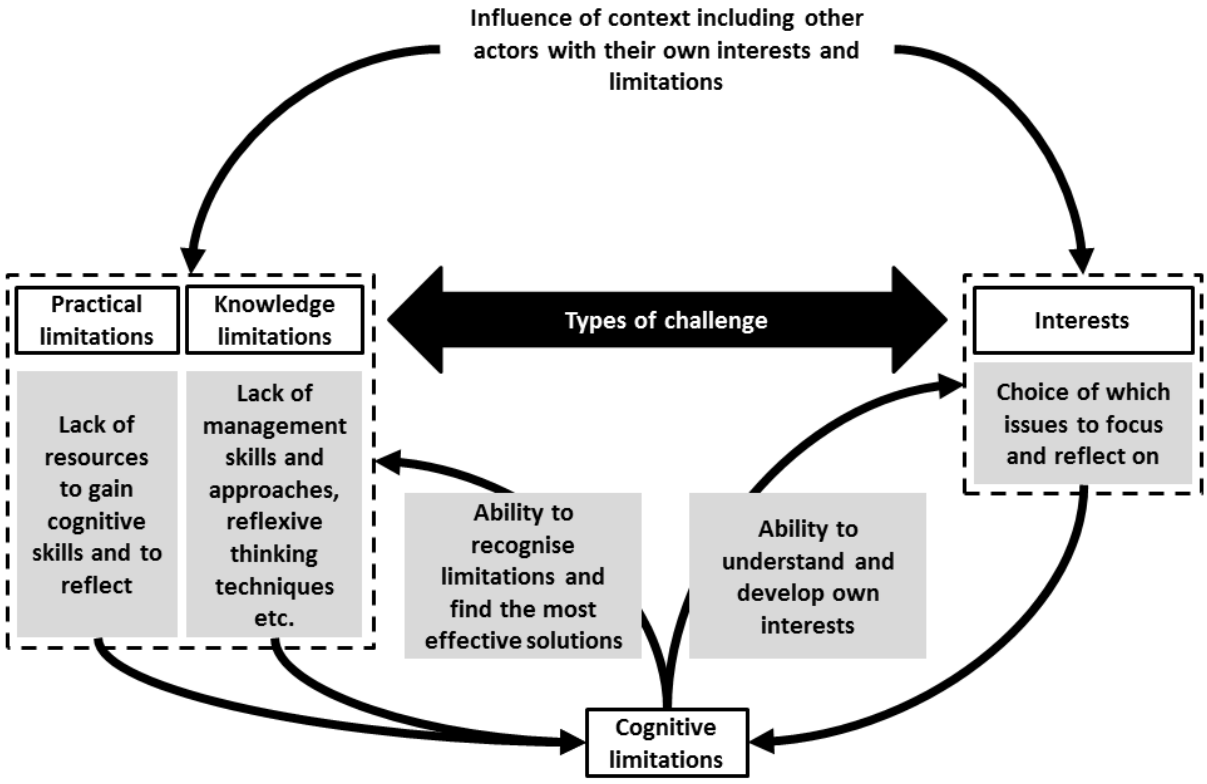

Fig. 5: Interaction of categories of challenge to the implementation of GHG mitigation measures in Welsh livestock agriculture. White boxes = challenge categories; grey boxes = specific aspects of the categories relating to Cognitive limitations; thin arrows = direction of interactions. Specific challenges to change lie on a continuum (large black arrow) between Practical and/or Knowledge limitations and the Interests of those involved.

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3.6. Comparison with applied literature

Consistent with previous findings of heterogeneity in the interests, motivations and perspectives of Welsh livestock farmers (Morris et al., 2017; Wynne-Jones, 2013) the current study revealed a complex mix of inter-related challenges to the implementation of GHG mitigation measures, reinforcing the view that a simple economic (profit maximising) model of the actions of the farming community in Wales is not sufficient to understand challenges and support positive change. A comparison between the themes (the least abstracted level of analysis) arising from the current study, and those derived from a global review of factors affecting the implementation of climate-friendly agricultural practices (Wreford et al., 2017) showed subtle differences between the studies, with some of the issues tackled at different levels (Supplementary Material D). However, despite the unique aspects of the Welsh livestock sector (Morris et al., 2017; Wynne-Jones, 2013) the whole range of barriers and drivers relevant to climate change mitigation in the global context (Wreford et al., 2017) was identified in the current study. Although this discussion does not break down current findings by sector, of the 29 themes identified, 24 were derived from both the dairy and the sheep and beef system workshops and interviews, indicating that there were no major sectoral differences in the range of challenge themes (although individual challenges and the relative importance of themes differed by sector). These findings, supported by a similar high degree of overlap with those of Feliciano et al. (2014), suggest that despite regional and local heterogeneity in the specific challenges facing farmers, diverse regions and systems face similar *types* of challenge.

Combining the categories affecting change into a conceptual framework (Fig. 5) illustrates how the problem-centred categorisation cross-cuts the individual-centred approach of recent studies focussed on identifying segments or typologies of farmers to guide improved interventions, such as Hyland et al. (2016b) and Morris et al. (2017). It aligns more with problem-centred conceptual

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frameworks such as Feliciano et al. (2014) offering a different perspective of the system in which the interests of different groups interact with external limitations.

3.7. Comparison with behavioural change models

Many elements of the framework derived from stakeholder data (Fig. 5) can be found in behavioural change theory. The category 'Interests' is most relevant to theoretical approaches to understanding the factors underpinning motivations and behaviours. However, given the purpose here of gaining an overview of types of challenge, the data do not facilitate the investigation of such theoretical underpinnings (e.g. the development and influence of underlying values and beliefs) but instead focuses on the range of expressed motivations and perceptions and their interaction with other challenge categories. A useful subject of comparison in this respect is the Individual Social Material (ISM) tool developed for Scottish government, which synthesises a range of theoretical approaches into a single model for addressing practical issues relating to climate change adaptation and mitigation (Darnton and Evans, 2013). The division in the ISM tool of behavioural influences into individual, social and material factors is supported in the case of mitigation challenges in Welsh livestock agriculture, by the emergence of categories relating to Interests (individual and social factors), and Practical and Knowledge limitations (material factors). Here, the use of a grounded theory approach also enabled factors and perspectives which might be missed by fitting data to a pre-defined framework, to emerge (Glaser and Strauss, 1967). The categories revealed make two departures from ISM, integrating elements from other areas of research and adding some novel perspectives.

The first difference relates to the category of Cognitive limitations. Cognitive factors are recognised in several ways in the literature. Psychological studies of farmer decision making focus on the

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cognitive biases that influence deliberative choices. Mankad (2016) describe how cognitive bias affects rational choices, in the form of mental short-cuts that draw on our beliefs and perceptions to simplify large amounts of complex, potentially incomplete incoming information – in relation to farming, this results in individualised logical frameworks and informally developed internal rules. The ISM framework (Darnton and Evans, 2013) considers specific types of cognitive bias, such as discounting, framing, loss aversion and mental accounting. Existing cognitive beliefs can create cognitive dissonance when we are exposed to new evidence that conflicts with established approaches (Mankad, 2016).

Behavioural models such as the Theory of Planned Behaviour (Ajzen, 1991) separate intention from action, extending interventions to change behaviour from the level of changing actions to that of changing intentions. Cognitive bias, as described by Mankad (2016), fits into such models as a factor affecting intention; trying to alter specific cognitive biases is revealed as a more long-term strategy for achieving change, than altering actions without changing intentions, which may lead to only transitory change (Noguera-Méndez et al., 2016). This position is consistent with the siting of cognitive biases within the 'Individual' category of the ISM model (Darnton and Evans, 2013) and the treatment of them as imperfections to be tackled.

In social psychology, cognitive processes have long been recognised in relation to decision making in general; Jager et al.'s (2000) 'Consumat' consumer choice model focuses on the interaction of uncertainty and the effectiveness of current actions in meeting needs. The model predicts that, when needs are better satisfied, and uncertainty low, actors repeat previous behaviours, moving towards imitation of others as their uncertainty increases. When there is low need satisfaction, actors use deliberative reasoning (weighing up different options) to identify better courses of action

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under low levels of uncertainty, moving towards comparing their actions with those of others as their uncertainty grows (social comparison). Several elements highlighted within the category of Cognitive limitations described here, indicate the applicability of this model to challenges to change in livestock agriculture – these include the role of habits, tradition and the influence of social factors (e.g. views of family, community and other farmers) as well as the importance of uncertainty on choices. Insights from the Consumat model have been applied in the field of vulnerability assessment, with the use of multi-agent based models allowing the social context and individual attributes of actors to be incorporated into predictions about likely vulnerability to change (Acosta-Michlik and Rounsevell, 2005; Acosta-Michlik et al., 2014). However, these studies often focus on predicting behaviour and recommending adaptation measures based on assessments of limitations (including cognition) rather than on tackling the causes of cognitive limitation.

Here, the concept of Cognitive limitations indicates the importance of cognitive processing in relation to the implementation of climate change mitigation measures in Welsh livestock systems. It encompasses the effects of cognition both at the level considered by Jager et al. (2000) in the continuum between more reasoned choices (deliberation or social comparison) and automatic choices (repetition or imitation) and at the level of cognitive biases arising within reasoned choices. Changing intentions is costly in terms of time (Noguera-Méndez et al., 2016) and could be viewed as a transaction cost in relation to the implementation of change; addressing Cognitive limitations is a mechanism for reducing this cost by facilitating more effective thought processes, also allowing wider and more complex factors to be considered. This re-framing and clarification of the role of cognitive factors can be shown by considering which ISM factors relate to the category of Cognitive limitations, and how this goes beyond the explicit role of cognitive bias within the ISM factor 'Costs and Benefits' (Table 2). The category of Cognitive limitations separates the issue of how to align

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attempts to influence decisions with existing cognitive biases, from the issue of how to best hone cognitive skills, including becoming aware of and developing more effective mental short-cuts.

Although cognitive barriers to change have been recognised in some studies of climate friendly farming, Wreford et al. (2017) judge them as relatively unimportant in relation to the implementation of climate friendly agricultural practices globally. One reason may be that the authors use a narrower definition of cognitive limits than that used here and in the social psychology literature; for example, they consider the competing pressures facing farmers, and the need for robust management strategies to deal with climate change risks and uncertainties, but do not relate this issue to cognition. The findings presented here suggest that the importance of cognitive processes needs to be more fully and widely recognised in relation to implementing climate change mitigation measures in agriculture, and specifically that Cognitive limitations can be treated as a focus for intervention to improve uptake, rather than as a fixed problem to be worked around.

Table 2: Comparison of ISM factors and Cognitive limitations. Bold type indicates where cognitive aspects are considered explicitly within ISM

ISM factor	Description	Framing within the Cognitive limitations category	Role in relation to Cognitive limitations category
Agency	The confidence to undertake a different activity	The confidence to undertake and then rely on a thought process dealing with a complex system – distinct from the confidence to undertake actions	Determinant of level and nature of Cognitive limitation in given cases
Skills	The ability to undertake particular activities	The skills to make decisions about complex systems under conditions of Cognitive limitation – strategies for developing and applying effective	Determinant of level and nature of Cognitive limitation in given cases

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		mental short-cuts	
Time and Scheduling	Allocation of time to competing tasks	Allocation of time to thinking about different competing problems (which are prioritised, which considered in-depth, the extent to which short-cuts are applied)	Available time is an external element, prioritising the use of time an internal choice. Lack of time is another determinant of the level and nature of Cognitive limitations in given cases
Costs and benefits	How people make choices, including **cognitive bias** (mental short-cuts, e.g. discounting, framing, loss aversion, mental accounting)	Cognitive biases are framed as strategies to facilitate choice-making under Cognitive limitations – habits of thought that make decisions easier to make	Strategies for dealing with / symptoms of Cognitive limitations
Habit	Automatic, repeated actions that may be supported by the specific context	Habits reduce the apparent complexity of the system being weighed up, simplifying choices	Strategies for dealing with / symptoms of Cognitive limitations

The second way that current findings depart from behavioural change approaches is that the category of Interests encompasses recognition of the interests of the supply chain and customers as challenges to implementing change, consistent with recent political economy studies considering climate smart agriculture. Newell and Taylor (2018) argue that, at the global level, agro-business and fund-seeking institutions act to direct the climate smart agriculture agenda towards solutions

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consolidating current global food production systems within a neo-liberal market framework. The findings presented here show the relevance of such issues to on-the-ground changes in the Welsh livestock agricultural sector. Such challenges were exemplified by the role of suppliers as information providers, the use of farm data by suppliers and customers to direct farmers' choices (e.g. companies developing breeding indexes and processors), the availability of mitigation solutions, and the direct effect of policy and global context as external pressures. Power relationships and their consequences can often be left unchallenged under pragmatic approaches to change, which seek consensus rather than revealing and discussing conflicts (Johansson and Lindhult, 2008). Research projects engaging stakeholders often take such pragmatic approaches, focussing on exploitative (making better use of current systems) rather than exploratory solutions, and may not support the transformative approaches that could be necessary to tackle the challenges of climate change (Martin et al., 2013).

Behavioural change models recognise the importance of understanding that other actors influence the group on which change is focussed, and that the behaviours of such actors are affected by the same factors as those affecting farmers' choices (Mankad, 2016). Using such theories to implement change relies on those involved reflecting on their actions (Morris et al., 2012). However, the problems associated with determining what changes are implemented, how and why they were chosen lies beyond the scope of behavioural change approaches, which focus on facilitating pre-determined change. Despite such issues being recognised in the applied literature on the implementation of climate-friendly changes (Wreford et al., 2017) they may not always be considered by policymakers seeking the practical support offered by behavioural change tools. The findings here highlight the importance of acting with awareness of the ethical issues relating to the use of behavioural change approaches (Clavien, 2018). As well as having social justice implications, ignoring or marginalising the consideration of critical elements may hinder implementation efficacy.

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An example is the role of historical context in shaping stakeholder responses to engagement (Ison et al., 2007). Here, experiences of past afforestation and the flooding of valleys were associated with suspicion of government and reluctance to embrace new production systems or accept payments in exchange for reducing current agricultural production.

The current study asked stakeholders to consider broadly the challenges to implementing GHG mitigation measures, to gain an overview of the scope and types of challenge to change. As a result, there were limits to the depth of investigation of specific challenges. More detailed investigation is needed to better understand specific components of the challenge categories, to consider how challenges differ for specific types of individual, in relation to specific concrete mitigation measures, and in relation to more local geographic and systemic contexts. This would include incorporating work on the impacts of different perceptions of climate change amongst farmers (Barnes and Toma, 2012; Hyland et al., 2016b) and other stakeholders, which were not put forward by stakeholders in the current study as challenges to change. This omission is likely to reflect the fact that those who reject the idea of climate change would be unlikely to engage in research focussed on implementing GHG emissions reduction measures. In principle, differences in perception would fit within the 'Interests' category of challenges as defined here, affecting the motivation for action, but may also reflect Knowledge limitations associated with understanding the concept of, and evidence for, climate change. The scope of the current work could also be extended through research to understand the relevance of the conceptual model developed to other farming sectors (e.g. cereal, horticulture or mixed farming) or to the related challenge of implementing climate change adaptation measures. While understanding challenges to change is an important first step in developing effective policy, further work is needed to consider i) how and to what extent different approaches to implementing change tackle the categories of challenge identified, and ii) what the potential impacts of different strategies are likely to be.

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5. Conclusions

The findings presented indicate that the implementation of GHG mitigation measures in livestock agriculture will require the application of trans-disciplinary understanding to enable specific challenges across the four challenge categories to be tackled effectively. In particular, efforts to implement change should recognise the underlying role of Cognitive limitations as a challenge to change and the need for critical examination of how and by whom change is determined, implemented and governed. The conceptual framework developed provides a tool to support policymakers in identifying challenges to the implementation of GHG mitigation measures in livestock agriculture, and subsequently in designing policies tailored to effectively tackle them.

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Supplementary Material A: Interview guide

The four questions below are to be asked regarding mitigation measures for the following areas of the farm: *feed*, *animal husbandry and breeding*, *manure management*, *land management*, *nutrient management* and *energy efficiency**

1) What are the main current issues for farmers in Wales in each topic area? (Beyond mitigation – so we are aware of potential trade-offs/challenges relating to the context of our work)
2) What would be your main concerns about GHG mitigation measures in these areas? (Provide examples from list if required to ensure correct understanding*)
3) What challenges would you foresee to implementing mitigation measures in these areas? **
4) What solutions might help to overcome the challenges you have listed?

*See **Supplementary Material B** for full descriptions of farm areas, and examples of potential mitigation measures (used to provide additional clarification to interviewees as required)

**Responses to question 3) provided the findings reported here, as well as answers to question 2) where these were framed by respondents as challenges to change

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Supplementary Material B: Farm area descriptions and example mitigation measures used to support interviews and facilitate workshop activities

Table A1: Areas of the farm used to focus discussions about GHG mitigation measures and challenges relating to implementation. Within each area facilitators had information on the types of option (mitigation measure) included, and some examples. This information was used to help participants understand the types of measure being considered, to ensure responses were relevant and reflected understanding of the types of change entailed in climate change mitigation.

Areas of Farm	Types of Option	Brief Description	Examples
Feed	Animal diet (improved management)	Optimisation of diet which involves a change in management of diets only	Optimise (reduce) crude protein levels; ensure balanced nutrients; phase feeding (increasing system efficiency)
Feed	Animal diet (investment)	Optimisation of diet which requires investment in equipment, tools or infrastructure	Precision feeding; monitoring feed intake
Feed	Feeding supplements	All feeding strategy options that involve additional supplements fed to animals	Feeding plant secondary compounds; Ionophores (e.g. Monensin); nitrification inhibitors
Animal husbandry and breeding	Optimal breeding strategy / breed	All breeding options included - which is optimal will depend on specific farm circumstances	Use of breeding indexes to improve production efficiency of animals in given environment, using breeds adapted to conditions
Animal husbandry and breeding	Husbandry (improved management)	Changes in husbandry that require only a change in practice	Monitoring health; early weaning; improved fertility management (improving system efficiency)
Animal husbandry and breeding	Husbandry (investment)	Changes in husbandry that require some investment in inputs, equipment or infrastructure	Altering housing for improved health and efficiency; vaccination; periparturient care; use of AI (improving system efficiency)
Land management	Land management to optimise current system (management)	Ensuring that the current production system is managed to minimise emissions	Take stock off wet grassland; rotational grazing; reduce reseeding frequency

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			(increase production efficiency and/or increase soil carbon storage)
Land management	Land management to optimise current system (investment)	Investing in the current production system to minimise emissions without increasing production	Tracks for animals to avoid soil compaction; add deep rooting plant species to sward
Land management	Land management to alter environmental conditions	Changing/maintaining the landscape in which production occurs (field boundaries etc.) without changing production system	Maintain hedges & boundary/field trees; restore peat soils; trees to control bracken
Land management	Land management: new production systems	Changing the production system to reduce emissions and provide new economic outputs	Agroforestry options - fast rotation coppice or orchards with grazing, feed crops with trees
Nutrient management	Fertilization (improved management)	Changes in timing and application which do not require new equipment or inputs	Apply fertilizer in spring, not autumn; split application into several doses
Nutrient management	Fertilization (Investment: sward/land, material additions)	Changes in fertilization practice that involve a change in fertilizer type or additional work on the land	Direct incorporation of manure into soil; use of slow release fertilizers
Nutrient management	Fertilization (investment: equipment, monitoring)	Changes in fertilization practice that involve new equipment or monitoring devices etc.	Regular soil testing for pH and nutrients; application of slurry with trailing shoe; precision application
Manure management	Optimising current manure system (management)	Ensuring management of current manure management system is optimal for minimising emissions	Fast removal of excreta from housing; lower levels in slurry tanks and reducing stirring
Manure management	Optimising current manure system (investment)	Investing to ensure the current manure management system (existing infrastructure etc.) is efficient as possible in minimising emissions	Additives to manure; bulking agents; increase litter depth
Manure management	Investment to create optimal manure system	Investing to change the manure management system to one that minimises emissions	New covered storage; new housing, Anaerobic digestion
Energy efficiency	On-farm energy efficiency (management)	All energy efficiency options that involve only changes in practice	Regular maintenance of equipment and vehicles, following an energy management plan
Energy efficiency	On-farm energy efficiency (investment)	All energy efficiency options that involve new fixtures,	Energy efficient lighting, refrigeration heat

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	tools, equipment, infrastructure	recovery, electric vehicles

Supplementary Material C: Description of themes drawn from the data

Initial coding of the data from interviews and workshops revealed the following 29 themes; from these and with constant comparison between them and the underlying data, the four categories of challenge to change described in the main text were identified. Each theme is listed with a brief description of the content of the data included within it.

Accepted opinions

1. In working practice – choices may be made on the basis of tradition or advice from previous generations with little questioning or consideration of alternatives. Farmers may act as a result of traditional or deep rooted views that may not appear rational. These types of action can be seen as ways to simplify complex problems (principles or pre-determined perspectives guiding action, rather than taking each individual choice on a case-by-case basis from scratch, which can be time consuming and complicated). Working things out once and then subsequently following a set of rules and beliefs based on it saves time and effort – where this works well, it is a way to avoid re-inventing the wheel and to incorporate previously gathered experience and skills. However, it can also represent a constraint to change if critical thinking is lost, if environment and context begin to change (new technology, climate change, changing demand, new scientific knowledge) altering what works best, or if new information shows that there are limits to such practices (such changes, e.g. in scientific thinking, might also affect trust (2)). Given the different experiences of farmers and differences in their sources of advice, there is likely to be individual, local and regional differences in how tradition affects practice. In the context of this challenge, new information might be better converted into general principles for action that farmers can apply themselves, rather than large amounts of case-specific complex advice.

2. Trust – Preconceptions and beliefs about who should be trusted or not, based on previous experience or assumptions about the motivations of those providing information. In the same way as for 1) these approaches can reduce complexity but may also become outdated if systems and motives alter over time versus those of the farmer. Particularly in relation to new science, knowledge, and therefore recommendations, often changes over time.

Awareness and availability of knowledge

Information may not be available about the effects of some changes, available information may not be of a good enough quality, or farmers may not be aware of relevant information. This creates problems as, for example, uncertainty in relation to contracts and prices increases the risk attached to making changes. Questions about what information should be provided can also affect the information on which farmers are able to base their choices (the extent to which providers filter

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information). There may be issues with the communication of advice and information between generations, with knowledge being lost.

Availability of solutions

1. Lack of any solution to implement – a lack of available solutions can affect three different types of option i) Changes reliant on new research and/or technology which is not completed, fully understood or fully developed ii) changes which create potential trade-offs or side-effects that need their own solutions to make the change acceptable and iii) changes which require a wider understanding of a system than previously used.

2. Practical problems with implementation – solutions may have been found but a viable version for use on farm may not yet exist (issues with costs, systems fit, reliability etc.).

3. Supply limitations – sometimes the supply of inputs required to implement researched and viable options does not exist due to economic constraints on suppliers (e.g. widely distributed customers and high transport costs, need for contractors to invest in new equipment to provide new service) or because the change entails the use of an input already used for another purpose and therefore scarce. There may also be issues with the supply of research in particular disciplines/areas, and with a broader decline is the agricultural service sector.

Complexity of systems

1. At farm level – farmers may not be keeping track of all aspects of the farm (e.g. accounts) and therefore choices are made without considering all aspects of the different options (which aspects are prioritised for consideration is then related to both knowledge (e.g. of relevant interactions and processes) and motivation). Changing the system can entail processing a lot of additional information, and the knowledge and training required may mean outside support is needed to identify the best options, creating a cost. Time may also be required to step back and reflect on the system as a whole and in the longer term. Over time, continually weighing up a range of different interacting factors day by day becomes increasingly mentally draining. Self-confidence in relation to the changes made may be affected as more and more factors need attention, limiting likely change through increased (perceived) risk. Complexity can be added to by, e.g. i) diversification (and this loss of specialisation can reduce productivity) ii) complexity and amount of new information, iii) complexity in systems of applying for support and in regulatory systems.

2. At sectorial level – farming systems across Wales are diverse, and current practice also varies widely (as a result of variation in the other challenges expressed)

Costs of communication

Knowledge exchange has a cost, and in addition more comprehensive forms (e.g. one to one advice) are more expensive. These may be costs for information providers such as government wishing to

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improve performance (including relating to working out how to best communicate complex issues), or costs to farmers needing to gain information through testing or external advice. In the latter case, such costs may be unavoidable if the farmer does not have time to gather the information him/herself, or if specialist equipment is required (e.g. testing for disease). Access to some information may depend on IT skills, developing which also entails cost. There are barriers to providing information, in addition to barriers to implementing change, and there may be a trade-off between the costs of information provision and its effectiveness.

Customer preferences

1. Nature of preferences – the supply chain may not support market differentiation or particular types of farmer-led change to products or marketing in all cases (e.g. depending on the product, region etc.) – customer preferences may not align with societal needs and may constrain farmer choices.

2. Changing preferences – if changes in farm practice focus on altering consumer demand, the transitory nature of consumer preferences must be considered – a system more responsive to consumers may not align with policy objectives long term (e.g. consumers losing interest in food carbon footprinting). In addition, because changes are often long term, by the time they are implemented the market may be demanding something different. These factors increase the risks associated with making changes based on current demand.

3. Linking preferences to production – even when customer requirements align with societal requirements, farmers may not be supplying products aligned to those demands; this may be, e.g. i) a result of a lack of reward for improving their product or practice to meet demand (e.g. they do not get a premium for producing more suitable products), taking away the incentive to change, ii) a lack of ability to meet more vigorous demands due to system constraints (e.g. dairy beef systems rely on dairy offspring and so are limited in terms of their options for improving meat quality) or a lack of skills, or iii) may be associated with issues of information flow in the supply chain, linked to the interests of customers (processors, retailers etc.) (see other challenges)

External pressure affects decision making and adds to complexity

1. External changes – political, economic and environmental changes beyond the farm and the sector (e.g. Brexit, novel diseases, changes in weather conditions) add time pressure and complexity to choices, and farmers may need support to deal with this effectively. Uncertainty about policy and economic context affects farmers, increasing the risks associated with change; the industry may need to use resources to deal with potential change, rather than reacting to it when it arrives.

2. Unbalanced priorities – external pressures relating to specific issues can create imbalances in what is prioritised, and result in unintended consequences (e.g. focus on TB and not think as much about other diseases). This can include pressures that encourage one type of change, which might not be appropriate everywhere.

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Financial position of farm

1. Lack of reserves of money to make changes – integrated approaches are not likely to be realised if farms are at their financial limits. Investment has been low for many years (even decades) with a chronic lack of funds.

2. Financial uncertainty – investment is less likely when farmers have short or uncertain contracts to supply their produce, and would be likely to increase with more certainty and stability; without a safety net there is a big risk associated especially with systemic change. As infrastructure investment adds value to the farm, this type of expenditure may be preferred as there is less risk associated with it.

3. Constraints in financial planning – there is a 3 year investment cycle, so change may be delayed, with investment less towards the end of each cycle; there may also be issues in relation to opportunities for investment. Short term financial management may also be an issue.

4. Constraints in financial services and support from banks and tax system

Historical context

Changes that displace (or are perceived to displace) farming in favour of societal benefits may evoke memories of previous painful top-down change (flooding valleys etc.). Changing from one production system to another can also mean breaking with deep historical traditions of a particular type of farming, in an area or within a particular farm.

Identity as farmers

A specific source of motivation, developed in different inputs, relating to how farmers might be motivated by improving their status (in their own eyes and in the eyes of the local community, including their families) and how farming provides them with a purpose and with meaning. This identity can be damaged or threatened by 'support' that affects actions that they see as part of their farming identity, or by attacks (perhaps in the national press) on their image. It can also drive the adoption of practices not aligned to profit maximisation. This motivation or perspective in particular may affect the efficacy of policy approaches that use money as an incentive, with the assumption that profit is the ultimate goal.

Initial cost

Change might require a large initial investment, which may be economically unfeasible or present a high level of risk for the farmer, even if in the long term they would benefit financially.

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Measuring effects of change

Farmers may not know how they are currently performing, and may not be able to effectively monitor future changes in performance, reducing their motivation to make a change, and/or to continue to implement it in the longer term – informal, poor quality approaches to assessing change may even incentivise actions that worsen efficiency (e.g. overfeeding). Where effects only emerge in the long term (pace of change) and when complex drivers (e.g. variation in weather) affect outcomes and confound evidence of improvements, issues relating to measuring change may be greater. Farmers may need support to improve monitoring (including collation of data etc.) in order to overcome the costs associated with it. The motivation for a farmer to monitor (which will have a cost) can relate to the value placed on the object of the monitoring (e.g. animal manure may not be perceived as an important resource).

Measuring implementation

It may be hard to tell if certain changes have really been implemented, affecting monitoring and enforcement

Non-monetary risk of change

Changes may carry risks that farmers are aware of but which may not have been spotted by policymakers (or may not be highlighted by suppliers) either for other parts of the system or in the long term. These include animal welfare, disease and the consequences of changing agricultural land to forestry. A lack of knowledge may lead to sub-optimal actions taken due to a perceived risk of not taking such actions (e.g. blanket use of antibiotics from fear of disease).

Non-price product value

The values and demands of customers affect the uptake of options that may affect product quality or the story associated with a product. Farmers have to consider the image of their product (e.g. to avoid taking actions that may not damage actual product quality but affect consumer perception of product quality). They may also have to consider how retailers perceive the perceptions of consumers, as well as what those consumer perceptions actually are. Reducing cost at the expense of product value or its story may not always be the best option economically.

Pace of change

Changes may occur over the long term and be incremental when some options are implemented, meaning that farmers see only gradual improvement over many years – this can affect the motivation to make and sustain such changes.

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Poor quality supply

Especially for novel systems and options, products supplied may be poorly designed or not well-proven, causing problems for farmers, pollution incidents etc., and requiring regulation to improve quality and reduce risk (link to policy and regulation – up-to-date with new conditions)

Regulation and policy

1. Restriction on autonomy – top-down regulations can restrict local choices and lead to unexpected / unwanted consequences. They can prevent farmers reacting to change in the way they would wish to (this might be positive or negative in relation to societal needs) not recognising farmer expertise. This includes the impact of specific sanctions (such as instant fines) on decisions to invest.

2. Adapting to changing conditions – the context of decision making (from weather conditions to changes at industry level) changes constantly. Policy and regulation may be left behind and not have the intended effect.

3. Disjointed regulations and policy – *ad hoc* policy fixes to individual problems, and complex policy and regulatory frameworks result in unintended consequences (e.g. removal of trees). This can be a particular issue when novel systems arise which create new interactions and incentives and change old ones in unexpected ways. There may be negative consequences, new opportunities may be unintentionally curtailed or the benefits of certain actions overlooked. Farmers may apply their own priorities to inconsistent policy and support the parts they like against those they do not (e.g. using no-till as argument to repeal glyphosate ban). Complexity can also make it hard for farmers and other stakeholders to understand the options and make effective choices.

Risks of sharing information

Information that is shared might be used in ways that have a cost to a stakeholder (e.g. for a farmer information about farm location in high risk TB areas) discouraging openness

Running costs

1. Economic disincentives for change – ongoing costs for systems maintenance need to be considered, as well as initial cost when making a change. When changes involve increased (ongoing) costs that outweigh the benefits to farmers, support will be required for change to occur. This will also be true when greater benefits might be made from a different change (e.g. hedgerows reducing productive area). Paid labour must be included in costs (linking to time constraints); assessment of costs needs to be comprehensive. Finally, if farmers work or invest (perhaps with funding) to increase efficiency, the supply chain may simply reduce prices, taking away the incentive to make changes, because they do not gain the benefits

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2. Long term running costs – running costs may continue indefinitely, and so there may be an incentive for changes to be reversed when support ends, or for the use of cheaper systems of maintenance that may cause safety/pollution risks etc.

Skill limitations

1. Novel solutions require new skills – many new options or changes in practice require farmers and workers to have new skills in order for them to be effectively/safely implemented; this includes not only technical skills but also (for example) the ability to work with other farmers and groups to manage shared systems such as common land, as well as being able to manage more diverse systems.

2. Lack of skills and training – a lack of approaches such as Continuous Professional Development among farmers is a problem, especially when novel change requires new skills, and may not be currently part of the ethos in the sector. A lack of management skills may be the limiting factor in a system, rather than an issue of viability for the system per se. Skills need to be better shared between generations to improve continuity. Education needs to be improved to take account of the sustainability agenda and the need for high skill levels.

3. Staff turnover – when farm staff change often it can be hard to ensure that workers are trained and have the skills they require to undertake different tasks. This may result from poor employment conditions.

Social risks of change

Farmers who implement change may face social criticism from other farmers, local people or family. If they are asked to work together, there may be social disagreements or animosities that create a risk relating to involvement. Other aspects of interaction (e.g. farms as competing businesses) may compete with social pressures/benefits in terms of what choices are made. Some changes (e.g. to breeds) might be particularly risky in social terms, given the strength of traditions.

Specific Motives

A selection of specific motives applied (implicitly or explicitly) to farmers. Comments are often framed in terms of suggesting what motives solutions should address (e.g. health and welfare, economy. Motivations beyond economic were suggested. The nesting of motivations is implied (e.g. yield is described as a focus for grassland management, while hedges are assumed not to be a priority due to the need to increase productivity – but are these ultimate motives, or related to other goals – economic success, job satisfaction, image etc.).

Suppliers' interests

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Suppliers of all farm inputs (including advisors and other farmers selling animals and vets) have an interest in selling their product, and in giving information consistent with maximising their sales. Currently farmers may have limited access to independent advice, and therefore make choices based on incomplete or misleading information. Any stakeholder with their own set of interests may seek to hinder change that acts against (or is perceived to act against) those interests, or to suggest apparent solutions that are in fact in their own interests and not in those of others. Customers along the supply chain (e.g. processors and the ultimate retailer) may act together to reduce farm prices, while suppliers such as breeders may work with customers and restrict the choices and opportunities for farmers.

Systems fit

1. Practical limitations of current systems which prevent or produce additional barriers to change – seemingly straightforward change can require the implementation of wider systemic changes (to infrastructure or practice) or may not be practical at all given the location of the farm, the size of the farm, or the type of land (including ownership). A linked system may prevent particular types of change (e.g. genetic improvement in sheep systems is linked across hill, upland and lowland farms) Issues may relate to the capabilities of farmers as well (e.g. a generalist without time to become an expert in each area of work on a small farm, or a specialised farmer without time to learn new skills such as hedgerow management); this links to skills limitations and time/effort/labour.

2. Other people implementing options – when land is managed by stakeholders other than the farmer owning the land, there may be no incentive for long term investment or careful management (link to priorities). Contractors on land (e.g. to maintain hedgerows) may cause damage to fields if the farmer is not able to manage access. Challenges may also relate to fitting cooperative approaches to current systems focussed on individuals and competition, and the fact that the delivery of societal goods affected by landscape-scale change often requires the application of such approaches. Communal activities can be challenging, especially when farmers now buy and use more machinery and employ less labour (few machines and the need for labour often spurred past cooperation) and the potential of such approaches needs to be understood in different contexts.

Time/effort/labour

1. Physical limits to work of farmer and workers – new options often require additional work, not just finance, and where time is already short; this may be the limitation, rather than financial costs. The easiest, rather than the most efficient options might be chosen. This issue is particularly important in the context of an ageing farming population with less energy and a need to reduce workload.

2. Long term commitment – physical effort may need to be maintained in the long term, bringing up issues relating to motivation and sustainability. The cost-effectiveness of a change might rely on long term commitment to use of the new system, so issues around sustaining effort long term are a risk and barrier to change

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Trade-offs

Implementing many mitigation options involves trade-offs between parts of the system (e.g. good quality slurry for AD means nutrients not going into the animals) trade-offs between benefits and costs (post-AD slurry has higher nutrients and therefore needs to be injected to avoid emissions; can improve breed genetics but must avoid inbreeding) trade-offs between new and old practices (woodland reduces agricultural land, diversification to off-roading damages soil quality and agricultural value) trade-offs between the long and short term (training may be needed and increases farmer capabilities, but may not have time for it.

Understanding motivations

Importance of understanding what drives farmer behaviour, be it economic success, family security etc. and how these things interact with each other. For example, economic success may be a goal in itself, or it may be a means to achieve security for the family. These motivations may limit the effectiveness of some solutions (e.g. farmers are competitors so in some cases may not want to work together if they prioritise winning this contest at a local level). Under limitations of time and complexity, the motives that are most valued may crowd out others. Motives may also be divided into short and long term, and these may trade off (e.g. payment for woodland planting versus reducing long term flexibility to use (and sell) the land). The most important motivations for some involved in agriculture may lie outside the farm, so that the system itself has a relatively low priority – this may reduce the efficacy of using incentives. Different perspectives on what motivates farmers may affect how problems are perceived and the types of solutions put forward, and this may cause problems if such perspectives are not critically assessed in the light of understanding. Top-down restrictions or targets that do not appear (to farmers) to be related to their goals, or seem to go against them, can make issues seem like government problems, not theirs.

Understanding novel systems

Issues relating to information are particularly acute for novel systems – there might be a lack of certainty about the viability of such systems, and those implementing them are likely to have limited knowledge about the detail of their operation and how to avoid problems and maximise benefits. It might also be hard to identify the different options available. Potential benefits or risks may be overlooked, and therefore poor quality choices may be made. Farmers (and other actors) will therefore need advice about the new system, and in some cases it may be that some aspects are not fully understood by anyone, creating uncertainty.

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Supplementary Material D: Comparison of findings with barriers described by Wreford et al (2017)

Table 4: Comparison of initial themes with a global review of the barriers to and drivers of the implementation of climate friendly agricultural practices (Wreford et al., 2017)

Barriers from Wreford et al (2017)	Initial themes from current study	How the current study themes differ from similar themes in the review
Land tenure, existing infrastructure, structural issues (farm size and fragmentation)	Systems fit	Included in both studies
Farmer age	Specific motives, Systems fit	Age per se is not viewed as the challenge, rather the issues that can arise as a result of age under specific circumstances are considered as barriers
Education (lack of)	Skills limitations	Skills limitations refer to education and practical skills, which goes beyond the review. This may be due to the differentiation here between a lack of skills versus a lack of knowledge about implementation
Lack of financial benefit	Specific motives	Economic motives were grouped under the broad range of motives shared by participants; the practical limitation of lack of funds or finance was treated separately under costs and 'financial position of the farm'
Initial costs	Initial cost, Systems fit	Divided the issue of costs associated with the infrastructure needed before a change can be made (systems fit) and high costs of the change itself. Incorporates the issue of cash flow – benefits may be long term, expenditure short term
Hidden/transaction costs (e.g. evaluation, monitoring)	Regulation and policy, Awareness and availability of knowledge	Included under regulation and policy and more broadly links to cost of identifying and accessing information and solutions
Credit availability, Financial capacity	Financial position of farm	The availability of financial services and the financial capacity of the farm were grouped together. The comparison highlights that financial institutions are suppliers
Farming identity and tradition	Specific motives, Identity as farmers	The themes in the current study are really nested – identity as a farmer emerged as a particularly important specific motive
Emotional and cultural attachment to land	Specific motives, Accepted opinions, Social risk of change	Included as a specific motive, and might also be associated with the acceptance of previous ways of working and systems, and the social (family, local community) influences on farmers
Perception / awareness of climate change	Specific motives	Not directly mentioned (probably due to the explicit reference to climate change mitigation in the workshop title and as the subject of interviews) although it would fit under 'specific motives'.
Experience of climate change	Specific motives	Wide ranging specific motives were identified, but not including experience of climate change, probably due to mitigation focus
Risks of change and uncertainty	Understanding novel systems Non-monetary risks of	Transformative solutions may be less understood by the farmer, supplier and researchers, while especially in a local context, farmers might see environmental or

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	change	biodiversity risks not recognised by policymakers (relating to homogeneity in policy)
Resource pressures	Time/effort/labour	Recognised here and in the review
Competing pressures for resources	Complexity of systems	Competing pressures were included as indicators of systemic complexity, that being the challenge - separating out the issue of cognitive limitations from that of competing motives
Production impact	Trade-offs	Production was one of the trade-offs identified, despite the framing of discussions to emphasize mitigation options that avoided production loss/gain
Lack of information on options & implementation	Availability and awareness of knowledge, Availability of solutions, Understanding novel systems	A lack of information was divided into that stemming from poor communication or farmer engagement, and that stemming from a lack of fundamental (scientific) knowledge (availability of solutions). This also overlaps with suppliers interests' (independence of advice)
Communication method and source	Costs of communication	Includes limitations of communicators
Commercial contracts, Supply chain constraints	Risks of sharing information, Suppliers' interests, Customer preferences, Poor quality supply, Availability of solutions, Customer preferences, Non-price product value	These two themes in the review were covered by a range of themes, being characterised in terms of the interests and limitations of other actors in the supply chain (encompassing researchers as suppliers of knowledge, and customers as the final consumer)
Lack of institutional support (industry bodies etc.), Policy absence, Narrow range of policy instruments used, Impact of non-mitigation policy, unintended policy consequences	Regulation and policy	Lack of institutional support was not explicitly raised except in relation to government as an institution, and (implicitly) in relation to knowledge limitations and uncertainty. Issues of narrow, complex or conflicting policy, and of unintended consequences were elements of Regulation and policy
Values and motives[1]	Specific motives, Identity as farmers, Customer preferences, Suppliers' interests, Social risks of change	Identity as farmers and the interaction of farmers with the interests of others (e.g. social motives for change) were separated. Participants did not directly refer to underlying personal values, but these might be extrapolated from analysis of specific motives
Hostility due to past policy and policy fears	Historical context	Extended to policy in other areas (e.g. reservoir building) as well as previous climate change policy
Homogenous policy	Regulation and policy, Understanding motivations, Systems fit	The need for heterogeneous policy is widely recognised; this was divided into the challenge of gaining understanding of what is happening, and the challenge of implementation
Carbon leakage through reduced competitiveness	Trade-offs	Carbon leakage formed part of the explanation to participants defining mitigation options
Lack of recognition for change (inventory limits)	Measuring effects of change, Pace of change	Also includes monitoring on farm to support the farmer (especially with gradual change farmer may be discouraged from continuing), as well as recognition for changes in country's inventory
Lack of ability to check implementation	Measuring effects of change	Considered as issue for top-down systems (farmers have incentive to avoid implementation).
Biophysical limitations	Systems fit	Included as part of systems fit

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Pressures (scarcity)	External pressure	Defined as pressures that imposed limitations, while in the review pressures are viewed as drivers of change through scarcity – this is partly explained by the joint focus of the review on mitigation and adaptation
	Running costs	Issue of ongoing costs and commitment (including beyond the timeframe of incentives) not mentioned specifically in review

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